This Page Is Inserted by IFW Operations
and is not a part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

IMAGES ARE BEST AVAILABLE COPY.

As rescanning documents *will not* correct images, please do not report the images to the Image Problem Mailbox.

THIS PAGE BLANK (USPTO)

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : H04N 7/133 — A1

(11) International Publication Number: WO 93/12613

(43) International Publication Date: 24 June 1993 (24.06.93)

(21) International Application Number: PCT/US92/10644

(22) International Filing Date: 10 December 1992 (10.12.92)

(30) Priority data:
807,117 13 December 1991 (13.12.91) US

(71) Applicant: AVID TECHNOLOGY, INC. [US/US]; Metropolitan Technology Park, One Park West, Tewksburry, MA 01876 (US).

(72) Inventor: PETERS, Eric, C. ; 80 Carleton Road, Carlisle, MA 01741 (US).

(74) Agent: PASTERNACK, Sam; Choate, Hall & Stewart, Exchange Place, 53 State Street, Boston, MA 02109 (US).

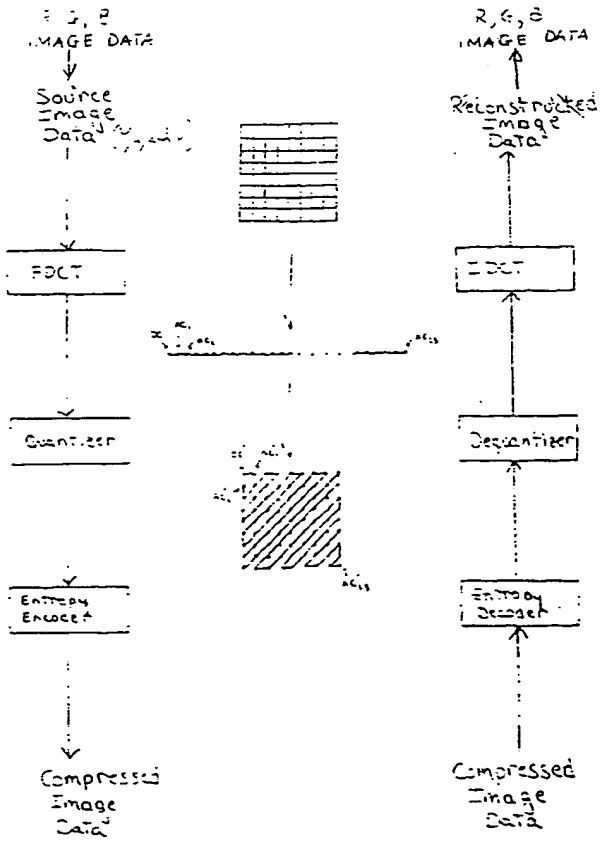
(81) Designated States: AU, CA, CS, HU, JP, KR, PL, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: QUANTIZATION TABLE ADJUSTMENT

(57) Abstract

The method for adjusting quality during image capture includes computing a discrete cosine transform of a digital image to create DCT coefficients. A quantization table is generated that specifies frequency bands to be filtered and the DCT coefficients are digitized using the quantization table. It is preferred that the DCT coefficients be ordered in a zig-zag sequence to facilitate run-length encoding.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FR	France	MR	Mauritania
AU	Australia	GA	Gabon	MW	Malawi
BB	Barbados	GB	United Kingdom	NL	Netherlands
BE	Belgium	GN	Guinea	NO	Norway
BF	Burkina Faso	GR	Greece	NZ	New Zealand
BG	Bulgaria	HU	Hungary	PL	Poland
BJ	Benin	IE	Ireland	PT	Portugal
BR	Brazil	IT	Italy	RO	Romania
CA	Canada	JP	Japan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo			SE	Sweden
CH	Switzerland	KR	Republic of Korea	SK	Slovak Republic
CI	Côte d'Ivoire	KZ	Kazakhstan	SN	Senegal
CM	Cameroon	LI	Liechtenstein	SU	Soviet Union
CS	Czechoslovakia	LK	Sri Lanka	TD	Chad
CZ	Czech Republic	LU	Luxembourg	TG	Togo
DE	Germany	MC	Monaco	UA	Ukraine
DK	Denmark	MG	Madagascar	US	United States of America
ES	Spain	ML	Mali	VN	Viet Nam
FI	Finland	MN	Mongolia		

QUANTIZATION TABLE ADJUSTMENT

Background of the Invention

This invention relates to hardware designs coupled with software-based algorithms for capture, compression, decompression, and playback of digital image sequences, particularly in an editing environment.

The idea of taking motion video, digitizing it, compressing the digital datastream, and storing it on some kind of media for later playback is not new. RCA's Sarnoff labs began working on this in the early days of the video disk, seeking to create a digital rather than an analog approach. This technology has since become known as Digital Video Interactive (DVI).

Another group, led by Phillips in Europe, has also worked on a digital motion video approach for a product they call CDI (Compact Disk Interactive). Both DVI and CDI seek to store motion video and sound on CD-ROM disks for playback in low cost players. In the case of DVI, the compression is done in batch mode, and takes a long time, but the playback hardware is low cost. CDI is less specific about the compression approach, and mainly provides a format for the data to be stored on the disk.

A few years ago, a standards-making body known as CCITT, based in France, working in conjunction with ISO, the International Standards Organization, created a working group to focus on image compression. This group, called the Joint Photographic Experts Group (JPEG) met for many years to determine the most effective way to compress digital images. They evaluated a wide range of compression schemes, including vector quantization (the technique used by DVI) and DCT (Discrete Cosine Transform). After exhaustive qualitative tests and careful study, the JPEG group picked the DCT approach, and also defined in detail the

various ways this approach could be used for image compression. The group published a proposed ISO standard that is generally referred to as the JPEG standard. This standard is now in its final form, and is awaiting ratification by ISO, which is expected.

The JPEG standard has wide implications for image capture and storage, image transmission, and image playback. A color photograph can be compressed by 10 to 1 with virtually no visible loss of quality. Compression of 30 to 1 can be achieved with loss that is so minimal that most people cannot see the difference. Compression factors of 100 to 1 and more can be achieved while maintaining image quality acceptable for a wide range of purposes.

The creation of the JPEG standard has spurred a variety of important hardware developments. The DCT algorithm used by the JPEG standard is extremely complex. It requires converting an image from the spatial domain to the frequency domain, the quantization of the various frequency components, followed by Huffman coding of the resulting components. The conversion from spatial to frequency domain, the quantization, and the Huffman coding are all computationally intensive. Hardware vendors have responded by building specialized integrated circuits to implement the JPEG algorithm.

One vendor, C-Cube of San Jose, California, has created a JPEG chip (the CL550B) that not only implements the JPEG standard in hardware, but can process an image with a resolution of, for example, 720 x 488 pixels (CCIRR 601 video standard) in just 1/30th of a second. This means that the JPEG algorithm can be applied to a digitized video sequence, and the resulting compressed data can be stored for later playback. The same chip can be used to compress or decompress images or image sequences. The availability of this JPEG chip has spurred computer vendors and system integrators to design new products that incorporate the JPEG chip for motion video. However, the implementation of the chip

in a hardware and software environment capable of processing images with a resolution of 640 x 480 pixels or greater at a rate of 30 frames per second in an editing environment introduces multiple problems.

It is often desirable to vary the quality of an image during compression in order to optimize the degree of data compression. For example, during some portions of a sequence, detail may not be important, and quality can be sacrificed by compressing the data to a greater degree. Other portions may require greater quality, and hence this greater degree of compression may be unsuitable. In prior implementations of the JPEG algorithm, quality is adjusted by scaling the elements of a quantization table (discussed in detail hereinbelow). If these elements are scaled during compression, they must be correspondingly re-scaled during decompression in order to obtain a suitable image. This re-scaling is cumbersome to implement and can cause delays during playback. The present invention is a method that allows for quality changes during compression to enable optimum data compression for all portions of a sequence, while allowing playback with a single quantization table.

Summary of the Invention

This invention relates to an apparatus and method for adjusting the post decompression quality of a compressed image. The image quality adjustment is performed by constructing a quantization table that specifies the high frequency image components to be filtered, and by subsequently filtering out those components specified by the table.

Brief Description of the Drawing

Fig. 1 is a block diagram of a video image capture and playback system implementing data compression,

Fig. 2 is a schematic illustration of data compression and decompression according to the JPEG algorithm.

Description of the Preferred Embodiment

A block diagram according to a preferred embodiment of a system for capture, compression, storage, decompression, and playback of images is illustrated in Fig. 1.

As shown, an image digitizer (frame grabber) 10, captures and digitizes the images from an analog source, such as videotape. Image digitizer 10 may be, for example, a TrueVision NuVista+ board. However, the NuVista+ board is preferably modified and augmented with a pixel engine as described in copending application "Image Digitizer Including Pixel Engine" by B. Joshua Rosen et al., filed December 13, 1991, to provide better data throughput for a variety of image formats and modes of operation.

The compression processor 12 compresses the data according to a compression algorithm. Preferably, this algorithm is the JPEG algorithm. introduced above. As discussed above, C-Cube produces a compression processor (CL550B) based on the JPEG algorithm that is appropriate for use as compression processor 12. However, other embodiments are within the scope of the invention. Compression processor 12 may be a processor that implements the new MPEG (Motion Picture Experts Group) algorithm, or a processor that implements any of a variety of other image compression algorithms known to those skilled in the art.

The compressed data from the processor 12 is preferably input to a compressed data buffer 14 which is interfaced to host computer 16 connected to disk 18. The compressed data buffer 14 preferably implements a DMA process in order to absorb speed differences between compression processor 12 and disk 18, and further to permit data transfer between processor 12 and disk 18 with a single pass through the CPU of host computer 16. The host computer 16 may be, for example, an Apple Macintosh.

JPEG Encoding and Decoding

Detailed discussions of the JPEG algorithm and its implementation are contained in "The JPEG Still Picture Compression Standard" by G.K. Wallace, in Communications of the ACM, Vol. 34, April 1991, and in "Digital Compression and Coding of Continuous-Tone Still Images, Part 1, Requirements and Guidelines," ISO/IEC JTC1 Committee Draft 10918-1, February, 1991, both of which are incorporated herein by reference.

Fig. 2 illustrates the key steps in data compression and decompression according to the JPEG algorithm for a single component of what will generally be a three-component image. In the JPEG standard, an image described in the RGB color space will be transformed into the YUV color space via a 3 x 3 multiplier prior to compression. This conversion sacrifices some color information, but preserves the more important detail information.

The algorithm works with blocks of 8 x 8 pixels from the image. Each 8 x 8 block is input to the compressor, goes through the illustrated steps, and the compressed data is output as a data stream.

The first step in the JPEG algorithm is a Forward Discrete Cosine Transform (FDCT). As described in Wallace, cited above, each 8 x 8 block of pixels can be thought of as a 64-point discrete signal which is a function of two spatial dimensions. The FDCT computes the "spectrum" of this signal in the form of 64 two-dimensional "spatial frequencies," termed DCT coefficients. The DCT coefficients represent the relative amounts of the two-dimensional spatial frequencies contained in the 64-point discrete signal. The coefficient with zero frequency in both dimensions is called the "DC coefficient" and the remaining 63 coefficients are called the "AC coefficients." Typically each pixel component corresponds to 8 bits, as is the case in 24 bit color. According to the JPEG algorithm, each coefficient is described by greater than 8 bits. In the C-Cube chip discussed above, the number of bits per coefficient is 12. Therefore, at this point, the

algorithm has actually led to an expansion, rather than a compression of data. However, since pixel values usually vary slowly across an image, most of the pixel information will be contained in the lower spatial frequencies. For typical 8 x 8 pixel blocks, most of the spatial frequencies at the high end of the spectrum will have zero or negligible amplitude. Data compression can then be achieved by "throwing out" these coefficients, which is the purpose of the next step.

The next step in the JPEG algorithm is quantization, wherein each of the 64 DCT coefficients is quantized in accordance with a 64-element quantization table. This table is specified by the user. The C-Cube chip allows user adjustability of this table via software inputs to the chip. Each element in the table is any integer from 1 to 255, according to the JPEG standard. Each element is the quantizer step size for a corresponding DCT coefficient. Quantization is achieved by dividing each DCT coefficient by its corresponding quantizer step size, and rounding to the nearest integer, a very lossy process. The elements of the table are chosen so that the generally large lower frequency components are represented by a smaller number of bits, and the negligible higher frequency components become zero. The goal is to represent each DCT coefficient by no more precision than is necessary for a desired image quality. Since the coefficients, therefore, depend on human visual parameters, the table is sometimes called a psycho-visual weighing table.

Compression is achieved by the use of run-length encoding, which puts an end-of-block code at the start of the sequence of zeros that will typically form the end of the 64 coefficient string. The zeros, therefore, don't contribute to the length of the data stream.

After the coefficients have been quantized, they are ordered into a "zig-zag" sequence, as illustrated in Fig. 2. This sequence facilitates the run-length encoding. Before going on to this step, it should be noted, that since the DC coefficient is generally one of the largest coefficients, and

furthermore since it is a measure of the average value of the 64 pixels in the 8 x 8 block, there is generally a strong correlation between the DC coefficients of adjacent blocks, and therefore, the DC component is encoded as the difference from the DC term of the previous block in the compression order.

The final step is entropy coding, wherein additional compression is achieved by encoding the quantized DCT coefficients according to their statistical characteristics. This is a lossless step. As this step is not as relevant to the methods of the present invention as those of the previous steps, the reader is referred to Wallace, cited above for a detailed discussion.

The above steps are essentially reversed, as illustrated in Fig. 1b, during playback. Here too, the reader is referred to Wallace for further details.

Image Quality Adjustment

From the above discussion, it can be seen that image quality can be adjusted by scaling the values of the quantization table. For higher quality images, the elements should be small, since the larger the elements, the greater the loss.

In prior art systems, this is precisely the technique used to adjust image quality during image capture. A variable quality scaling factor (1-255) called the quantization factor or Q-factor is used with JPEG to adjust the degree of quantization of the compressed image. For sequences requiring high quality, low Q-factors are used. For sequences in which quality can be sacrificed, high Q-factors are used. It can be imagined that a user may want to continuously adjust the quality over the range of the Q-factor at the time of capture as scenes change.

The problem with the above method is that if the quantization table values are scaled during image capture, they must be correspondingly

descaled during image playback. To illustrate the importance of this, imagine the result if the quantization table element corresponding to the DC coefficient is multiplied by a factor of 10 at some point during image capture in an effort to increase the degree of data compression. If at playback, the original quantization table is used (prior to the upward scaling), the DC coefficient will be 10 times too small. Since the DC component primarily corresponds to brightness, the result is dramatic.

The method of the present invention is an alternate method for adjusting quality during image capture which permits playback using a single quantization table. According to the invention, the DCT coefficients are filtered during image capture according to the following technique.

As has already been discussed, the DC coefficient is the most important in terms of human perception. The higher the frequency of a coefficient, the finer the detail it describes in an image. Humans are much less sensitive to these high frequency components. Therefore, according to the invention, if image quality is to be lowered to further compress the data, the high frequency components are filtered out. The cut-off frequency of the filter determines the degree of compression. This method is in clear contradistinction to the prior method of adjusting the Q-factor.

As described above and illustrated in Fig. 2, the coefficients are sequenced in a zig-zag pattern as part of the quantization step. A filter according to one embodiment of the invention can be characterized as a diagonal line indicating the cutoff frequency. The effect of throwing out the higher frequency components is a blur of the image to an extent determined by the cutoff frequency. This artifact is often acceptable, depending on the scene and the quality required.

Furthermore, the artifact caused by the filtering can be made more tolerable to the eye by adjusting the filter in the following manner. If in addition to throwing out all frequency components above cutoff, the

frequency components just below cutoff are muted, the artifact is made less harsh.

The filter described above can be created by hand-creating quantization tables. For all frequencies above cutoff, the table elements should be large, preferably as large as possible without overflowing the arithmetic of the system. For frequencies below cutoff, the table elements can be exactly as used in standard JPEG implementations. However, preferably, the table elements below but near cut-off are increased by some amount to mute the corresponding frequency components as described above. Preferably, this muting is greatest at cutoff, decreasing as the DC coefficient is approached.

The filter can be easily adjusted during image capture to control the degree of data compression by changing the quantization table. In one mode of operation, the filter is user adjusted. However, in another mode of operation, the filter may be automatically adjusted by the system when it senses bottlenecks forming.[1]

As stated above, the invention was developed as a method for adjusting quality during image capture in such a way that playback can take place in the absence of the history of such adjustment. It should be clear that this is achieved when the images are played back using the original quantization tables. This is because only the least important coefficients are affected by the filtering. In contrast, in the prior methods for quality adjustment, all coefficients were affected to the same degree.

Subsampling introduces artifacts called aliases to the signal. These frequencies can be predicted and removed by increasing the Q table entries for them.

---

[1] The interrupt routine gets activated on each frame. It computes the current frame size and compares it with the desired target size, then it adjusts the table by moving the filter cut-off frequency to approach the target.

What is claimed is:

1. Method for adjusting quality during image capture comprising:

computing a discrete cosine transform (DCT) of a digital image to create DCT coefficients;

creating a quantization table that specifies frequency bands to be filtered; and

quantizing the DCT coefficients by means of the quantization table whereby image quality is adjusted by scaling the values of the quantization table.

2. The method of claim 1 wherein high-frequency components are filtered out to further compress the data.

3. The method of claim 1 further including ordering the quantized coefficients in a zig-zag sequence to facilitate run-length encoding.

4. The method of claim 1 wherein the frequency bands to be filtered are user adjusted.

5. The method of claim 1 wherein the frequency bands to be filtered are automatically adjusted.

6. The method of claim 1 wherein only the least important DCT coefficients are affected during the quantizing step.

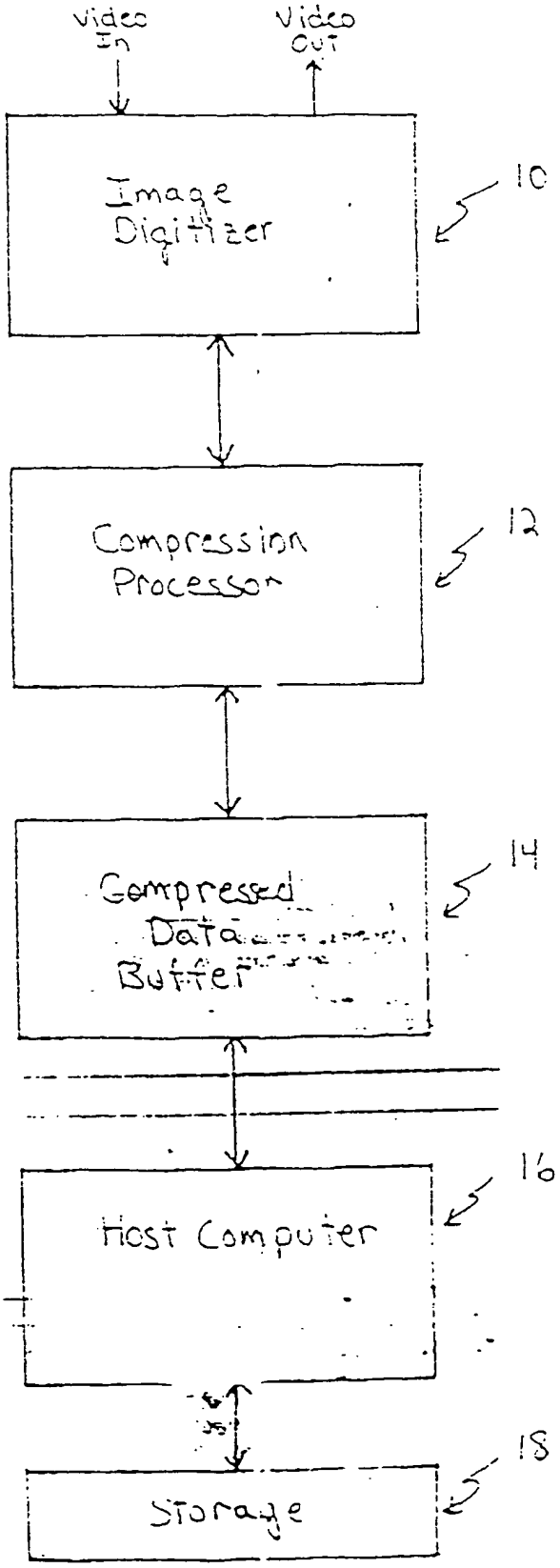

Video In
Video Out
Image Digitizer
10
Compression Processor
12
Compressed Data Buffer
14
Host Computer
16
Storage
18

FIG. 1

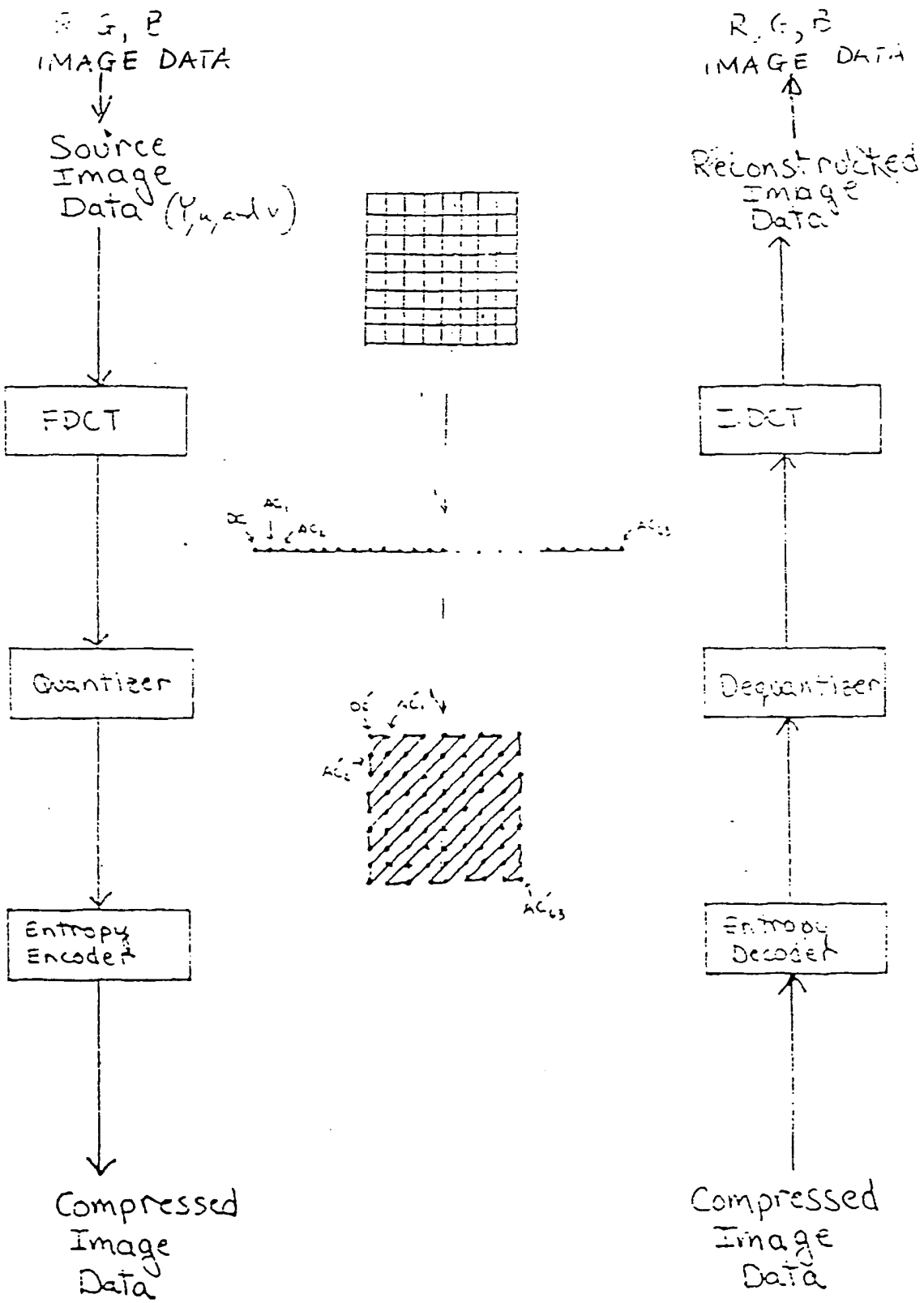

R, G, B
IMAGE DATA
Source
Image
Data (Y, u, and v)
FDCT
Quantizer
Entropy
Encoder
Compressed
Image
Data
R, G, B
IMAGE DATA
Reconstructed
Image
Data
IDCT
Dequantizer
Entropy
Decoder
Compressed
Image
Data

Fig. 2

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 92/10644

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 H04N7/133

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	H04N

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category[10]	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
X	US,A,4 982 282 (SAITO ET AL.) 1 January 1991 see abstract; figures 1,8,9,10 see column 10, line 1 - line 25	1-4,6
X	DE,A,3 940 554 (FUJI PHOTO FILM CO. LTD.) 13 June 1990 see abstract; figures 5,6,12,13 see page 7, line 14 - line 37	1-3,5,6
A	COMMUNICATIONS OF THE ASSOCIATION FOR COMPUTING MACHINERY vol. 34, no. 4, April 1991, NEW YORK US pages 30 - 44 G.K.WALLACE 'The JPEG still picture compression standard' cited in the application see the whole document	1-6

-/--

° Special categories of cited documents :[10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
18 FEBRUARY 1993	26. 02. 93
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	GIANNOTTI P.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	US,A,4 672 441 (HOELZLWIMMER ET AL.) 9 June 1987 see column 7, line 16 - line 23; figures 2,5 ---	1-6
A	US,A,5 038 209 (HANG) 6 August 1991 ---	
A	WO,A,9 114 339 (THOMSON CONSUMER ELECTRONICS S.A.) 19 September 1991 -----	

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

US 9210644
SA 68299

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 18/02/93

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-4982282	01-01-91	JP-A-	2156789	15-06-90
DE-A-3940554	13-06-90	JP-A-	2203673	13-08-90
		JP-A-	2158285	18-06-90
		US-A-	5170264	08-12-92
US-A-4672441	09-06-87	EP-A,B	0201679	20-11-86
		JP-A-	61242481	28-10-86
US-A-5038209	06-08-91	CA-A-	2050102	28-03-92
		EP-A-	0478230	01-04-92
		JP-A-	4288776	13-10-92
WO-A-9114339	19-09-91	AU-A-	7474591	10-10-91